

# DOCUMENT RESUME

ED 197 352

CS 206 038

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 TITLE Writing to Think about High School Chemistry.  
 PUB DATE 80  
 NOTE 76p.: M.A. Thesis, George Mason University.  
 Appendixes may be marginally legible.

EDRS PRICE MF01/PC04 Plus Postage.  
 DESCRIPTORS \*Chemistry: Discovery Processes: High Schools: High School Students: \*Learning Processes: Science Instruction: \*Study Skills: \*Writing (Composition): \*Writing Research: Writing Skills

IDENTIFIERS \*Journal Writing: \*Writing across the Curriculum

## ABSTRACT

An English teacher conducting research for a masters degree participated in a high school chemistry class and organized student journal writing in that class so that she could observe the effects of writing as a learning process. Based on the "thinkbook" writing that she and other classmates did, especially two students who served as case studies, several conclusions were drawn about students who wrote to think about chemistry, including the following: (1) these students wrote both for and to themselves to get the material straight in their minds: (2) they wrote because they were interested in understanding, not just memorizing, the material: (3) they needed to see the material in their own words and in their own order of thought, not only in the words and order in which the material was presented in class by the teacher: (4) they did not need to write about all the material: (5) they wrote when they were rested, when there were few internal or external distractions: (6) they sometimes used their writing later to check or refresh their memories: and (7) as a result of writing to think, they did not need the teacher to explain things over and over. Although writing to think is a procedure that may not be useful to all students, it has been shown to be an effective learning strategy that teachers should consider. (Additional suggestions for using this writing procedure are offered.) (RL)

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WRITING TO THINK  
ABOUT HIGH SCHOOL CHEMISTRY

by  
Anne Miller Wotring

A Thesis  
Submitted to the  
Faculty of the Graduate School  
of  
George Mason University  
in Partial Fulfillment of  
the Requirements for the Degree  
of  
Master of Arts  
English

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Summer Semester 1980  
George Mason University  
Fairfax, Virginia

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## ACKNOWLEDGMENTS

I wish to thank my esteemed colleagues, Pat D'Arcy, for her enthusiastic correspondence and Don Graves, for his direction and insightful words of encouragement.

Further, I am extremely grateful for the support of my thesis committee, Chris Thaiss, Bob Gilstrap and Don Gallehr, who encouraged me to write a readable work.

In addition, I want to thank the administrators of South Lakes High School, Reston, Virginia, a Fairfax County Public School, for permitting me to conduct my study there.

Finally, I want to thank Carolyn Lavallee, who taught me chemistry, and Laura Fanning, Tim Stanard, Jim Jeans, and Piera Pelligrino, my fellow chemistry students, without whose efforts my research question could not have been answered.

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## INTRODUCTION

### "Writing to learn" across the curriculum

The term "writing to learn" includes any kind of writing which is done by a student in the learning process. It includes the notetaking at the presentation of the material, the written work on a homework assignment, and the written answers on test questions. Educators have used writing in these ways for years although it hasn't been until recently that they realized the importance which writing has for their students beyond expediting the teachers' job of evaluating the students through their written efforts. Most teachers know that the activities of reading, listening, talking, and writing are all crucial to their student's ability to understand.

Recently writing researchers<sup>1</sup> have given the phrase "writing to learn" a more particular meaning. They have

<sup>1</sup> See the following articles and books: Barry Beyer, "Using Writing to Learn in History," The History Teacher, 13 (Feb. 1980), 167; Janet Emig, "Writing As A Mode of Learning," College Composition and Communication, 28 (May, 1977) 122; William F. Irscher, "Writing As A Way of Learning and Developing," College Composition and Communication, 47 (October, 1979) 240; Robert Parker ed., "Understanding, Teaching, and Assessing Writing: A Report," Rutgers U. Graduate School of Ed., May 1979 (includes excellent bibliography); Andrew Stibbs, Assessing Children's Language (London: Ward Lock) 1979.

seen how students learn by writing freely and personally about the subject in their own words and using their own experience. They suggest that teachers need to offer their students many opportunities to write in their own terms in a nongraded atmosphere about a school subject. In Writing and Learning Across the Curriculum (W&L),<sup>2</sup> the authors suggest "a personal log book" or "diary" as a means for offering students "expressive" writing experiences in school. Other researchers<sup>3</sup> suggest "journals" for the same purpose.

Last summer when I met Pat D'Arcy, co-author of W&L, I was about to embark on a writing research project. She suggested that, if she had the opportunity, she would join a class of high school students studying a subject she'd never taken and in which she didn't have an "aptitude." As a student she would keep "a personal log book" while she learned. In addition she would observe other students in the class who also wrote to learn. I was fascinated with the idea and knew just what subject I wanted to study. With D'Arcy's blessing and a promise

<sup>2</sup> Nancy Martin, Pat D'Arcy, Bryan Newton, and Robert Parker, Writing and Learning Across the Curriculum (London: Ward Lock Educational) 1976, p. 32.

<sup>3</sup> Toby Fulweiler, "Journal Writing Across the Curriculum," ERIC, ED 161073, 1978. (Includes excellent bibliography of works about journal writing.

that I'd let her know what happened, I became the only 29-year-old student in a high school chemistry class and set out to discover what happens when students write in personal terms about high school chemistry.

I had been led to believe early on in my school career that science and math were not for me. I had no "aptitude" in these areas. I did not take chemistry in high school because I had been convinced that it would be too hard and that I would do poorly if I tried. My mother got a "D" in it. I took biology and "Earth Science" to complete my science graduation requirements in both high school and college. I secretly liked them both, and secretly I wished I could know what chemistry was all about. When I realized that by doing research about writing I might get a second chance to go back to high school and take a subject I'd always been curious about but hadn't dared take, that the grade wouldn't matter, and that I'd have plenty of excuses for doing poorly, I was secretly excited.

#### My research constructs

Carolyn Lavallee, a colleague at South Lakes High School, Fairfax County, Virginia where I had taught English, enthusiastically agreed to let me become a student in her fourth period chemistry class. I attended daily, had a lab

partner, did the homework, took the tests, received grades, was known by my first name, and called the teacher by her last. I was a high school student again. My husband received my report cards in the mail and a stern call from the associate principal, my long time friend and colleague, when I cut class one day.

Carolyn also agreed to ask and encourage each student to keep what we called interchangeably a diary or a journal in which each would keep his thinking about chemistry. Each would include anything he had read, heard or done in class as well as any related thoughts from his experience. The students would write whenever they wished, or whenever the teacher thought we had gone over difficult or confusing material, or whenever I, as a student of chemistry, was confused or felt the need to write. I knew I would more naturally gravitate to pen and paper because of my background in writing than the other students even though they might be just as confused about chemistry. I asked her to direct the writings, whether they were initiated by me or her. I wanted her to make the assignments because I assumed the students might be more inclined to do them at her instruction than at mine, a person who was just another student in the class.

Although Carolyn "directed" the journal writing, she agreed she would not evaluate nor penalize students who did

or did not write. In fact, she didn't read the journals unless a student requested her to. The student decided if he wrote and what he wrote, and knew that I would want to read his journal for my research.

I quickly discovered that I didn't have time to be both a researcher and a chemistry student at the same time. I tried very hard to do both, to keep up with my own journal and the homework and labs, as well as to read the students' diaries each week or two and to talk to them about their writing. I simply didn't have enough time or energy so I decided to relax and enjoy learning and writing about chemistry without worrying about what was happening to anyone else. I knew there'd be time later to observe what happened to the other students.

This paper focuses on the experience of two students, Laura and Tim. A description of my experience follows, in the conclusion. The similar experiences of two others, Jim and Piera, are omitted from this paper. Jim's think-book was misplaced, and Piera's personal discovery of think-writing two years ago in addition to her chemistry writing deserves to be the topic of another paper.

#### Formulation of my question

I used the descriptive research model of Donald H. Graves, Director of the Writing Process Laboratory at the

University of New Hampshire, to ask and answer my research question: "What happens when students write to think about high school chemistry?" My original question had been, "What happens when students write to learn about high school chemistry?" However, in the course of doing the research, I came to see that the phenomenon which I observed in four students and experienced myself was, in fact, very different than what my original question was asking.

When we discussed the chemistry writing, the students and I never called it "writing to learn." I most naturally referred to it as "figuring out writing." Tim told me about the "get into it writing" he was doing. Laura said she did "write it out writing." At times, we also called it "getting it straight writing," "rough writing" (what Teddy Roosevelt did), and "practice writing." As Suzanne Langer notes in her work, Philosophy in a New Key,<sup>4</sup> the correct word is by nature symbolic and powerful in meaning. I realized I had to revise the term I had adopted from W&L. In the process of writing about my research, I came to see that no matter what we had called it, no material got "figured out," "straightened out," or "gotten into" by the writer, unless he was thinking about his material.

<sup>4</sup> Suzanne Langer, Philosophy in a New Key, 3rd ed. (Cambridge: Harvard U. Press) 1963).

People have written to learn for years. They find they can acquire and retain information if they write it down in their own hand. Some people take notes for this reason and others write out everything they know so they will remember it better. But thinking isn't necessarily part of this acquisition process. In addition, we commonly misuse the word "learn." At the dinner table children ritualistically tell their parents what they "learned" in school; what they mean is "were presented with." But presentation is only the first step in the learning process. Simplistically, after the student is presented with the material, he must do something with it before he can learn it. He may memorize it or he may physically work with it, but no matter what activity he pursues, his participation precedes the acquisition of knowledge. By the same token, the activity of thinking comes before learning is acquired. Writing for us was the visible physical activity of chemistry thinking which was going on invisibly in our heads. As we wrote, we could see what we knew about it. What we saw in our writing were questions we had; that is, we knew what we still needed to know. Or what we saw were answers; that is, we knew what we knew.

I use "thinkbook" in this chapter to denote the book in which we wrote about chemistry for the same reason. I revised my question. In the case study sections, Tim and

Laura refer to it as journal or diary because at that time we didn't know the new term. Students associate journals with English teachers; we were writing for chemistry. Diaries are for personal thoughts; chemical concepts are not personal. Notebooks are for recording the teacher's words; we were using our own. Logbooks are for keeping records of information; we weren't recording. Writing book is vague. Practice book and workbook imply drudgery; what we were doing was often invigorating and refreshing.

I believe that the redefinition of "writing to learn" to "writing to think" will be of great interest and help to writing researchers, educators, and students alike. It forms the basis for my future research in the field.

## LAURA

"It's usually better for me to [write] at night, after...all that...has time to rest.... I can think a lot better."

"I just started writing the things I didn't understand.... I started writing questions...[which were] all specific.... Then I brought them up to [the teacher] and she could answer them for me.... That way all my questions were cleared up."

"Some of the questions I would have never thought of [if I hadn't written]."

"I found that when it was time to study [for a test], there really wasn't much I had to study because I knew everything."

"If I did take the time to write it out, the confusion would be [resolved] or I would have questions to ask [the teacher] tomorrow."

Laura worked hard in all her subjects. In most classes she received superior marks. Chemistry was her most difficult and she worked especially hard to get anywhere from below average to excellent daily grades. Her favorite subject was World Civilization.

From her first entries it was evident Laura trusted me and was comfortable writing to me: "There have been many things I have learned so far in this course. As I was

watching the candle burn in lab 1-3, I remember thinking how dumb it was. To tell the truth, I thought that Mrs. Lavallee was a little strange for making us do it." In addition to her truthfulness, Laura carefully maintained perfect punctuation, handwriting, and sentence structure. Anything she crossed out, she crossed out neatly, with a perfectly straight line through it. Her only cross-outs were made at the completion of her effort, to edit out grammatical errors she made in the course of writing. For example, in the first writing she crossed through "was" and changed it to "is", making the entire writing in the present tense, and she crossed through an improper nominative pronoun "I" and changed it to the objective "me".

Laura explained later how she felt about doing the writing:

In the beginning, I thought it was the dumbest idea in the world. I was really mad, and I didn't want to do it. [But]...you and Mrs. Lavallee were really insistent, so I figured 'oh well, I'd better start writing.' I was really hesitant to write because I knew you were an English teacher.... I felt like it was an added thing, where the writing would have to be perfect.

But Laura wrote because she thought that she should participate in the research project which her teacher and I were encouraging her to do.

By the end of the first quarter, Laura was very frustrated with chemistry and writing. "Everything I was

writing wasn't helping me at all." She was writing to me and for me, as the researcher, about what she was learning in chemistry and how she felt about the class and the tests. Laura missed an "A" that quarter by one point. "I was kind of, real upset about that...." With a fresh grading period beginning, Laura vowed to work for an "A" the next time. She still felt that I, as an English teacher, couldn't help but silently evaluate her as I read what she wrote. She liked me and wanted me to like her and respect her intelligence. Laura felt encouraged by something I said. "You kept telling us to start writing what we learned and what [we] didn't understand."

With her overriding desire to learn the material so she could get better grades and a notion that it might be acceptable for her to actually write down things she didn't understand, Laura used her thinkbook to work through some metric conversion problems the class was given. She did her scratch work in the book she had previously reserved for writing only the things she was sure of. She had no idea of whether she would be able to do the problems. Her caution in writing was evident. Her earlier entries were in pen. The metric conversion problems were in pencil. She wrote with the security of knowing that she could erase anything which was too wrong or too messy before I ever read it.

This writing<sup>5</sup> showed the first evidence that she was writing to herself for herself. It looked quite similar to the writing a math student does to "show his teacher his work;" however, the difference was that Laura wrote all the thoughts going on in her head, not just those which related directly to the product of the problem. She wrote words which were extraneous to the product of the problem, the words of thought she was thinking to herself and for herself as she worked through and solved the problems. They were the clue that she was writing to and for herself.

Laura began the metric conversion problems by writing words of encouragement to herself. Her encouraging voice got her started by saying "okay ---." She wrote the conversion formulas as she had memorized them. She congratulated herself by writing "So far so good -- Now --". She proceeded to figure out the first problem by writing out the steps of her thoughts. When the problem was solved, she exclaimed on the paper, "I did it!" Laura turned the page and started another problem. When it, too, was solved, she did another. With two more completed, she began to feel more confident and wrote, "I think I'm catching on." She copied another, more complicated than the others. Again she couldn't help but exclaim to herself about her ability to solve equations she had thought were

<sup>5</sup> Reproduced on pp. 24-26 and pp. A1-A3.

impossible. After working through one more, she felt confident enough to stop. She felt she could do any of them now. She realized, though, that she still wasn't confident about "rounding off" numbers and so she wrote a few reminders to herself. With these recorded on the paper and in her mind, she confidently chided herself, "I better pass this dumb quiz. Don't forget!" She completed the writing by outlining to herself rules for determining the significant figures in an equation.

Laura's caution in her first think-writing entry carried over into her next, but in a different way. When she was confused and frustrated with her inability to understand, she often asked the teacher for help. But she wasn't always able to tell the teacher exactly what it was that she didn't understand. The teacher was frustrated, too, with general statements of non-understanding.

Whenever I went up to Ms. Lavallee... and said, 'I don't understand,' she couldn't help me...because...I didn't tell her what I didn't understand.... So, I started writing questions down.... I just started writing the things that I didn't understand and then I brought them up to her, and she could answer them for me and I could just...write them out.... That way...it was all specific and all my questions were cleared up."

Laura was delighted to find that she could write questions she thought of on her own about her own confusion.

"Some of the questions I would have never thought of....

When I went home and thought about it, new questions came up and so I would just write those down." Before this, she hadn't realized that she had the ability to ask the questions which could help her understand the material. She didn't yet have the confidence in her own ability to attempt to answer the questions for herself. She was still convinced she needed the teacher's help. She wrote the questions which she had discovered on her own and for herself so that the teacher could answer them for her.

In a few weeks Laura was taking complete responsibility for her learning. Not only was she still discovering and asking her own questions, but she now had discovered that she, herself, could often answer the questions she posed. She realized that writing helped her understand the material.

Laura wrote the entry on Thomson<sup>6</sup> and electrically charged particles with the confidence that she would be able to figure out the material on her own. She knew that if some of the material failed to make sense to her, she could always ask the teacher for help.

She began the entry with a reminder to herself which had great significance for her. She underlined "particle" four times and ended the sentence with three exclamation

<sup>6</sup> Reproduced on pp. 27-29 and pp. B1-B5.

points. Then she got into the material which she needed to think about. The key word for her was "Thomson." The reader can actually see and hear her thinking here. She wrote the name and paused and thought to herself, "'okay,' what do I know about Thomson?" Writing "okay" gave her time to think. She wrote the first thing which came to mind: "He did an experiment with a ball." That triggered her to think about the experiment: "If the ball is charged," and so on. She told herself what happened in the experiment. This caused her to wonder why that should happen. She asked herself "why?" and answered herself.

In this entry Laura was no longer concerned with perfect prose. Laura knew the rules of grammar well enough to know that "Because electricity interacts with a magnetic field" is a sentence fragment. But she was writing fast and was not thinking about the rules of grammar at this time. She was concentrating on chemistry. It was hard for her to think about two things like that at once and to do the kind of thinking required for both. She was only concerned about getting her thinking out on paper, not with demonstrating her knowledge of "proper writing."

At the end of line 12 she exhausted her train of thought and paused again to write the "okay" on line 13 and begin some new thinking. She wondered about the variables involved in the experiment. She answered her question (lines 14-17) only to realize that she couldn't follow

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"so" with a conclusion from the information she had. She realized that she had forgotten about a key occurrence in the experiment and couldn't draw the conclusion which she had been told was the correct one yet. Because she was writing while she was thinking, she saw where she was jumping to the conclusion too quickly. On lines 17-19 she parenthetically reminded herself that she "forgot about deflection." She began a section on deflection. She divided her thinking into sections like paragraphs except her indentations were reversed. Each section dealt with a new idea.

She defined her understanding of deflection on lines 19-20 and explained how it related to Thomson's experiment. She was evidently delighted with the information she had about Thomson and deflection because she felt the need to exclaim about what a "smart guy!" he was for discovering that deflection was "the arc of a perfect circle." With the exception of the "O.K.'s" and the reminder at the top, Laura often used parentheses to enclose the comments she made to herself about what she was thinking. She marveled at the scientist's work and stopped herself when she realized she had forgotten something important which she needed to write about so all the data made sense together.

"Now" gave her another chance to pause and recap in her thinking before she plunged into the next ideas which follow. Lines 25-27 were her first attempt at putting

together the information she had laid out in the three previous sections. She took a stab at making the connections. The minute she began to write, she realized the material couldn't make sense yet. She wrote, "Wait, that doesn't make sense," the thoughts a person sometimes says out loud when he realizes that the idea which seemed to make sense in his head doesn't make sense when he says it. Just as that person might try to rethink out loud, Laura attempted to get it straight on paper.

Laura knew it was okay for her to let lines 25-27 stand and didn't take the time to put scratch marks through them. She trusted the writing to know that the important thing was for her to go on and write some more, not to take the time to cross out what she had. She realized her purpose for writing was not to read and understand later on what she had written. She knew that once she had written and gotten it all straight, she wouldn't need to go back and read it later because she would already understand the information.

With her new attempt at puzzling it out, she felt closer to understanding and thought faster, using shorthand arrow signals to represent "increases" and "decreases." What she said on lines 30-31 seemed to make sense to her but she wanted to try the idea again, this time in other words, which were signaled by "or" in line 32. She

wondered why this happened. Her curiosity was peaked to want to wonder at what all this meant and to marvel at the knowledge she had.

Between lines 30-38 she got the idea straight and even drew a diagram to see even better how deflection works. In the next two sections she tried out her idea of deflection by setting up two hypothetical problems which she proceeded to work through so that they jibed with the idea she had set forth, and so that they agreed with each other. Again, she left the sentence fragment in lines 41-43, and the "than" on line 40 and 45. Laura knew the difference between "than" and "then" but couldn't be concerned with pursuing letter-perfect prose when she was more concerned with pursuing her understanding to its end.

At line 49 she needed to recap what she had just learned from writing out the hypotheticals. She listed the four variables involved. Then it occurred to her (lines 56-57) that there was one more variable which was known and so she noted this.

Then she wrote from her notes the exact words about deflection the teacher had given in class lecture: "Deflection is proportional to the charge of the particle and the strength of the magnetic field." As she wrote each word, she thought to herself "do I understand?" and, as she understood, she continued to write. With the writing of

these words, Laura checked to see that, indeed, her own train of thought and language had led her to the exact same conclusion. She saw that the teacher's words fit into her understanding of the experiment. The teacher's words, succinct and to the point, now made sense to Laura because she had played with the ideas in her own order and way.

On line 63 she wrote the equation which represented the idea expressed in 59-62. In lines 64-66 she copied another passage from her notes as if to say "yes, I understand this idea now too. These words make sense to me." So, she wrote the equation which represented the idea. Then she combined the two equations, as she had seen done in class. But this time, SHE did the combining, not the teacher. She could do it not because she had seen the teacher do it in class or because she had committed it to memory, but because she had worked it through herself. She knew how the two equations corresponded.

With the equations in place, both on the page and in Laura's head and in complete harmony with all her other information, she prepared a little quiz for herself. She knew each question was an important one to ask. She posed these questions, not because she knew the answers, but to see if she did. She knew she should if she didn't and would have to get help. But, by the time she had completed writing each question, she knew she knew the answer. As she saw that she could answer each, she did.

After the questions on lines 76-78, she replaced the conventional question mark with an arrow which pointed the way to the answer, as if to say, "I can ask the questions and I can also answer them. See??" These arrows reveal her delight at her ability to understand chemistry.

When a teacher delivers a lecture, he presents his own experience and knowledge of the subject. When a student hears the lecture, he applies his own experience and knowledge to the material presented. The teacher's ideas and order of presentation may be completely different from the student's own ideas and train of thought. It is difficult for him to listen to the new ideas and at the same time to relate them to his own ideas. Until Laura let the old and new ideas in her mind flow out, be seen, and mix together, she couldn't assimilate the ideas together so that all the information was in accord.

During the first quarter, she had followed her usual study habits, which meant she kept up with the material required on the day-to-day worksheets, labs, quizzes, exercises, and homework. Then, as Laura told it, "[on] the night before a test, I [had] to cram for everything and memorize everything." But, in chemistry, Laura found that

when I [wrote] down every single day what I learned, and I understood everything every day, I found that when it was time to study [for a test] there really wasn't much I had to study because I knew everything.... It's a lot easier doing it this way.... This

quarter in this class I haven't  
 had to [cram or memorize] once....  
 But you have to do it day-by-day....  
 Every single day you do have to  
 understand what's going on.

Laura had come to realize she didn't have to spend her energy cramming everything and memorizing everything if she spent her energy thinking about everything as it was presented. Previously, she had never actually thought about the material presented in chemistry because she never realized she could think about it or really understand it. In other words, not only did the writing enable her to think about a subject which was difficult for her, but it also enabled her to understand it. But even as Laura told me how she no longer had to cram to study on the night before a test, she didn't yet realize or understand that by discovering and asking questions about the material day-to-day, she was studying.

As the class progressed and Laura continued to write, she began to read over her writing before a test and found that even though she didn't cross things out which she knew were wrong at the time she wrote them, she could still tell which things were right and which were not.

Eventually, she changed her review habits. On the night before a test she would write

in my diary just everything I knew,  
 I didn't even look in my notes. I  
 wrote everything I knew, and then,  
 I checked my notes to see if I'd

left out anything or if everything  
I'd written was correct and it was."

She realized that the writing she did in her thinkbook was important for thinking about and figuring out chemistry. But for the purpose of reviewing for a test, she found it more helpful to read over her notes from the lecture. The notes organized the material in the most succinct and understandable way and were easier for her to read than to take the time to read her writing. The in-between-step of writing was crucial for her in being able to use the teacher's notes.

Laura found the class time she was given to write unsatisfactory for her purposes.

[Ten minutes in class] usually doesn't give me enough time because it takes me a long time to think.... In class, I seem really confused and I don't have everything straight in my mind.... It's usually better for me to do it at night after [class] because all that, that [the teacher] said, has time to rest. And I can think a lot better.

Her reasons shed insight into what happened to the information she had taken into her brain while she was in class. She could tell that her brain needed a chance "to rest," to mull the information about subconsciously until a little while later when it would be able to process it. To borrow an analogy from Pat D'Arcy,<sup>7</sup> this phenomenon is much

<sup>7</sup> Letter received from Pat D'Arcy, 6 April 1980.

like the process of photography. An image is made on the film when a picture is "taken" and is then "developed" over a period of time and under special conditions before it can become clear and forever-captured. For Laura, it took time and special conditions for the information she had been presented with in class to develop in her brain before it became clearly formed and not easily forgotten.

Laura discovered that she didn't have to write every day. She only needed to write over the period of time new material was presented. She collected the material in her head until she felt she had enough ideas which needed to be thought about and connected together. Laura explained,

Last night I didn't do [the writing]  
and I still...haven't thought about  
what she said yesterday at all, so  
I'm still really confused about it.  
But I know that tonight, if I did  
take the time to write it out, the  
confusion would probably be [resolved],  
or I would have questions to ask her  
tomorrow.

Laura's confidence in her ability to "write it out" and either be able to understand the information or to ask questions about it, is remarkable for a student who had little confidence about learning chemistry in the beginning. She knew that if she wrote she would be able to understand the information.

Laura's metric conversion writing (typed from her thinkbook)

Okay ---

$$1 \text{ km} = 1000 \text{ m}$$

$$1 \text{ hm} = 100 \text{ m}$$

$$1 \text{ dkm} = 10 \text{ m}$$

$$10 \text{ dm} = 1 \text{ m}$$

$$100 \text{ cm} = 1 \text{ m}$$

$$1000 \text{ mm} = 1 \text{ m}$$

So far so good ---

Now ---

$$10 \text{ m} = \underline{\hspace{1cm}} \text{ km}$$

$$? \text{ km} = 10 \cancel{\text{ m}} \quad \frac{.001 \text{ km}}{1 \cancel{\text{ m}}}$$

$$\begin{array}{r} .001 \quad 3 \text{ sig. figs} \\ \times 10 \quad 2 \text{ sig. figs} \\ \hline 000 \\ 001 \\ \hline 0.010 \end{array}$$

$$.01 \text{ km} = 10 \text{ m}$$

I did it!

$$? \ell = 250 \cancel{\text{ml}} \quad \frac{1 \ell}{1000 \cancel{\text{ml}}}$$

$$? \ell = \frac{250}{1000}$$

$$\ell = .250$$

$$.25 \ell = 250 \text{ ml}$$

$$? \text{ kg} = 2000 \cancel{\text{g}} \quad \frac{.001 \text{ kg}}{1 \cancel{\text{g}}}$$

$$2 \text{ kg} = 2000 \text{ g}$$

I think I'm catching on

$$? \text{ cl} = 10 \cancel{\text{ml}} \quad \frac{1 \cancel{\text{ml}}}{1000 \cancel{\text{ml}}} \quad \frac{100 \text{ cl}}{1 \cancel{\text{cl}}}$$

$$= \frac{10 \times 100}{1000}$$

$$= 1 \text{ cl}$$

$$1 \text{ cl} = 10 \text{ ml}$$

All right!

$$\begin{array}{r}
 ?d\ell = 7.7\cancel{8} \quad \frac{10}{1\cancel{8}} \\
 \frac{10}{77d\ell} = 7.7\ell
 \end{array}$$

Just remember to place the units in the right order so you can cancel out. Remember to go up to major unit if necessary & then proceed.

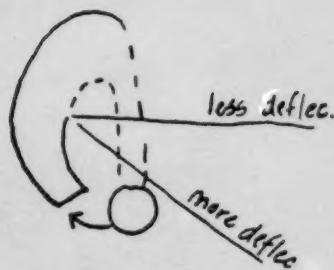
I better pass this dumb quiz  
Don't forget!

All digits are sig. figs  
All zeros between 2 #'s are sig figs  
All zeros after a # & after a decimal are sig figs  
All zeros after a # & before a decimal are sig figs

u = micro  
um = micrometer

Laura's writing on Thomson (typed from her thinkbook)

|                                                                                                                                                                   |    |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| Don't forget to pretend<br>that the ball is really<br>a particle!!!                                                                                               | 1  |
| <hr/>                                                                                                                                                             |    |
| Thomson →                                                                                                                                                         |    |
| O.K. He did an experiment<br>w/ a ball & a magnetic field                                                                                                         | 5  |
| If ⇒ the ball is charged, there<br>is a greater attraction<br>between the ball & magnetic<br>field. Why? Because<br>electricity interacts w/ a<br>magnetic field. | 10 |
| O.K. What if the mass of the<br>ball was changed? The<br>magnetic field would have<br>a harder time attracting the<br>ball. So --- (I forgot<br>about deflection) | 15 |
| Deflection is a change in<br>direction. Thomson<br>found in his experiments<br>that deflection was the<br>arc of a perfect circle.<br>(Smart guy!)                | 20 |
| Now ⇒ As the ball w/ the<br>larger mass goes through,<br>the deflection goes down.                                                                                | 25 |
| Wait, that doesn't make<br>sense.                                                                                                                                 |    |
| As mass of ball ↑ ,<br>deflection ↓<br>or                                                                                                                         | 30 |
| It takes longer for the<br>magnetic force to<br>attract the ball (Why?<br>because of the added<br>weight) & ∴ the deflection<br>or arc is not as curved.          | 35 |



If the balls speed is increased  
than deflection is less again.  
Because it takes longer for  
the magnetic field to attract  
it.

40

If the magnetic field is  
increased than the ball  
will have a greater deflection  
because the attraction is  
greater.

45

So far -- 4 variables  
involved.

50

- 1) charge of moving particle
- 2) speed of moving particle
- 3) mass of particle
- 4) strength of magnetic  
field.

55

The amount of deflection  
can be measured.

So 5 variables now.

deflection is proportional  
to the charge of the particle  
& the strength of the  
magnetic field

60

$$d = eB$$

deflection is inversely  
proportional to the mass  
and volacity of the particle.

65

$$d = \frac{1}{mv}$$

## Combine Equations

$$d = \frac{EB}{mv}$$

|                                |       |    |
|--------------------------------|-------|----|
| Can deflection be calculated?  | yes   | 70 |
| Can the charge of the particle |       |    |
| be calculated?                 | no    |    |
| Can the magnetic field be      |       |    |
| calculated?                    | yes   |    |
| Can mass of particle be        |       | 75 |
| calculated                     | ⇒ no  |    |
| Can speed of particle be       |       |    |
| calculated                     | ⇒ yes |    |

## TIM

"Since I [got] it confused even writing it, obviously, if I was just trying to hold it all in my mind, it would have confused me, probably even more."

"If you just try to sit there in your mind,...the ideas are all mixed up and hard to figure out."

"If I [hadn't written] it, I never would have thought about it until the day before the test."

"If I hadn't written it out, then I probably still would have been confused."

"I guess I was confused, and I kept writing to try to figure it out in my mind."

"It was more like just writing out what I [was] trying to do, even though I didn't know."

Tim's aptitude lies in the sciences including chemistry. He always sat in the front row, paid rapt attention to the teacher's lectures, and fearlessly asked any question which occurred to him in spite of occasional groans from the other students. He wanted to learn. Tim thought writing to think sounded interesting and was curious about my research.

At first he wrote everything to me and for me, as if he were writing me a letter recording the day's events in chemistry. His handwriting was very neat and his grammar flawless. Later Tim said, "It's usually hard for me to write for me because I'm used to writing for what...the reader is going to think about it."

In no time at all, he began writing for himself; however, he continued to write to me. He still wrote to tell me the material being presented, but he included, for himself, more detailed and specific information. With more complete information recorded daily in his own words, he realized he would be able to review easily and quickly for a test by reading through his thinkbook. At this point he used his thinkbook as a log book.

He was still concerned about his reader:

...if Anne saw this, I [would] want her to think that I know what I'm talking about.... To me...when [I'm] writing something..., even if it's nothing important, I think about correct grammar and correct punctuation, and does this sentence make sense? and is it clear? and all that stuff. And so if you're writing 'the electrons are negative,' you have to make sure that you say it right and it sounds good.

Shortly after he began writing for himself, Tim decided to "take" his lecture notes in his thinkbook along with his writing. He decided it would be convenient to keep all

his information recorded on the pages of one book. Hereafter, his journal shows pages of dated notes taken in class interspersed between dated entries of writing. He wrote the entries from his memory of the material presented in class. Although it often seemed to him redundant and inefficient to write the material over again from memory which he had already recorded in his notes on the previous page, he continued this practice, finding the rewriting helped him remember the material. He was "writing to remember." He was also "writing to check," for, after he made an entry, he always checked it against his notes to be sure the information he wrote from memory was correct and complete.

At this time, he recorded the material from rote memory and recall. He listed in sentences the facts he could remember and referred to his notes to continue the list for facts he could not recall. He didn't make connections between facts or put them in any particular order. He didn't draw any conclusions or look for any relationships. He didn't actually think about the material. Tim explained, "I just sort of write down what I think I learned." In other words, he wrote down the facts which were presented, not those which he had thought about. He made most of these entries in the ten minutes of class time allotted for think-writing or during his lunch period which preceded the chemistry class.

With the end of the quarter approaching and his grades falling short of his goals, he decided to get more serious about studying. The teacher lectured daily about electrically charged particles. She introduced three very important experiments which were historically based on one another. That is, it was necessary to understand the first, Thomson's, to understand the second, Millikan's, to understand the third, Goldstein's.

One day she was cut off in the middle of something important when the bell rang. Tim didn't have his usual time to write in class. The next day there was no time left again. On the third day without time to write, Tim knew he had to get all the material straight. He was really confused. That evening, he took home his thinkbook with his notes in it. This was the first time he had ever written about chemistry at home. Tim explained what happened:

I was really having problems with something. I didn't know what was going on.... I think it was like the day or a couple of days after we had actually done the lesson, and I went back to [my notes] and I said, 'what is this?'.... Instead of saying [to myself], 'now if Anne saw this, I want her to think that I know what I'm talking about...', I started just writing in my journal what I remembered....

He began writing about Goldstein's experiment.<sup>8</sup> He recorded the facts he remembered until he got to line 9.

<sup>8</sup> Reproduced on pp. 41-43 and pp. C1-C3.

There he found himself writing something which didn't jibe with information presented by the teacher. He couldn't continue to introduce any more facts onto the paper until he had the facts on the paper correct and in order. He realized he truly wasn't sure how Goldstein had set up the experiment and consequently wasn't sure about any of the facts he had written to that point.

I was writing about that drum that that guy made where he caught the oil drop.... I was writing along and I was putting... 'and then he had two negative plates...and the atom or the electron got attracted towards one.' And, all of a sudden, I say, 'Wait a minute! It wouldn't get attracted if it was negative!' And so I wrote that: 'it wouldn't get attracted if it was negative. This is wrong!' I wrote 'this is wrong.... Wait a minute. Let me...go back.' I wrote that down.

Seeing the confused material on the paper forced Tim to see his confusion. For the first time, he recognized that the words on the paper were the symbolic representation of the ideas which had come from his head.

Tim was incredulous that he had actually allowed himself to confess on a piece of paper that he hadn't understood something. By writing those words, he felt as though he had admitted to the world, or at least to me, that he didn't always understand everything. Tim took the chance and wrote these words to himself with no concern for the opinions of anyone else who read them. For the first time,

he realized that he was the only audience he needed to worry about when he wrote to think about chemistry. If he needed to write down "I am totally confused," then it was important that he write it. If he was thinking those words, then he wanted to write them along with the other words he was thinking. He realized that his need to get things straight was far more important than his need for the reader to see that he is smart because he understood everything.

He had written first that protons were sent through the chamber and, at this point, he wondered if that was wrong. He decided that perhaps this was the error causing everything else not to make sense and come together. So on line 13 he drew a diagonal line after the sentence which had led him to a dead end. He began again with an idea he thought of while writing. At line 15 he told himself that what he was writing presently "must" be right. Yet, by line 17, he obviously had run into another snag. From line 17 to line 21 he made his first cross-throughs.

It is important to know that he did not make the cross-throughs until he had almost finished with the writing. In other words, he did not know until later in the writing that what he had written on those lines wasn't going to continue to make sense with later things he wrote. As he added to the idea, he had to change and/or reword earlier ideas to make them all agree. What is crossed out now

remained uncrossed out until Tim did further writing and came to a point where again the information didn't continue to relate. When he realized the problem, he went back and made these cross-throughs and wrote in the correct information which made this section accord with the rest.

When he first wrote them, Tim wasn't totally sure lines 17-21 made sense but he left them anyway. He was frustrated. He knew he couldn't go any further in thinking about lines 17-21 as they stood. If he wanted to go on with this same train of thought, he would have to figure them out. He almost knew how it all went, but not quite, and it didn't seem important to work out what seemed at that point to be a small kink in the process. He was still in the habit of writing for other people; consequently, he didn't care about correcting fine thinking errors he sensed he was making in a writing few would see. He thought fine thinking errors were corrected in writing to help the reader read. He didn't know that the correction of a fine thinking error enabled the WRITER TO THINK through AND UNDERSTAND the material. If he had felt his own writing were important to him and not just to other people, he might have pursued that hazy line of thought. If he had known the relationship between writing and thinking, he would have realized the importance of puzzling out the information for himself, so that he could understand it.

Instead of taking the time to write the thought through again so that it made total sense, he shifted gears. He jumped to a new train of thought. He was sure he could pursue another thought successfully without ever having to work through the problem with the previous one. He began the new thought with "anyhow," a clue that he was jumping from his old train of thought to another, a clue which could foreshadow a bigger problem ahead. The "anyway" signified that "even though this previous statement doesn't make complete sense to me, in any case, I'm going to go on." He continued on with new facts of the experiment. In lines 25-28 he clarified the previous words for himself in the parenthetical statement. He simply reworded the idea he wrote into words that made better sense. He went on with little trouble until line 39 when he realized that what he had just written was VERY wrong.

He drew an arrow and gave himself the bad news, "But". He realized that the information in his head no longer coincided with what he had just written. To prove to himself that it wouldn't work, he next wrote this data from his head so he could see that it couldn't. Then he told himself to wait and think this through. He continued to write these thoughts on paper. He chose a plural subject "we" (in line 42) as if he were two people working on this problem together, as if these two people were talking about

the experiment, and one of them was going to try to set the other one straight about his misunderstanding. Tim started drawing diagrams which illustrated to his other self what was happening. Then he "okayed" himself as if to say to his other self, "I understand so far, go on."

At this point he went back and rethought some of the information about Millikan's experiment, even though when he had begun the writing, he had thought he understood it fully. He needed to understand it now, not in isolation, but as it related to Goldstein's experiment. After having done the writing about Millikan's work, he went back and crossed through most of those earlier troublesome lines (17-21) to make them agree materially and grammatically with his completely revised thought. What he had believed was a small kink in the process turned out to be an important kink in understanding the big picture.

At the time he talked to me about this writing, he scratched the two light diagonal crossout lines over lines 40-42. He did this because he said that he still couldn't believe that he had actually written those embarrassing words, and he considered this aside to intrude upon my reading and understanding of this section. He still hung on to the idea that I was reading his journal to appreciate his knowledge of chemistry.

The correction he made on lines 17-21 was his last word in that entry. That correction was the key to his

understanding all the experiments. He didn't need to continue to write about Goldstein's research because, with the correction, he had it straight in his head. He had accomplished his purpose for writing; his thinking process was complete and it didn't matter if his product wasn't. Had his purpose been to record everything about the experiments, he then would have written a complete, accurate and neat explanation of his understanding on another page.

Tim now knew that he didn't need help understanding the three experiments. He had had all the knowledge; he just needed to know what he had and get it in the right order. He had used his hand to write it down, his eyes to see it, and his brain to think about the connections it made.

In an interview, Tim told me about his usual learning experiences:

When the teacher is writing the thing on the board, you understand how she's doing it. But when you get home and look at the book, you have no idea. And then when she explains it the next day, you understand what she's saying, but you still would never be able to figure that out yourself.... She's almost telling you too much. She's telling...you... $a + b$  is going to equal  $c$ , but she's not telling you how you get there.... It's like Mrs. Lavallee is telling us something about the electrons. She says, 'okay, the electrons do that and they do this.' Then I get home and I say 'yeah, but, how did they do that or what happens if they don't do it?' That's when you get confused because you...sort of understand what they're doing but

not why they're doing it. And it's hard to understand what something does when you can't understand why they're doing it,...or what's going to happen when they do it, or why the other things don't do it.

He also commented on his experience writing in chemistry class:

Sometimes you get into it [the writing]..., meaning that you really want to do it, you really want to find out why it didn't work or what's wrong. Other times you'll just say, 'oh, well. I don't understand.' And you won't write down why you don't or what you don't [understand]. You just write you don't understand. [But when I'm serious about trying to understand,...it's easier to get into it and just write.... And so if you tried not to worry about whether it sounds good and whether it's correctly punctuated and you just write it, it's a little bit easier. But it's hard to [not worry]. It's like untraining the way you've been trained.... [When] I didn't have to stop and think about writing, I just thought about chemistry and...I just wrote what I was thinking.

Tim's January 22 writing (typed from his thinkbook)

## January 22 entry

We learned about the mass spectrograph. Goldstien devised this apparatus to measure the mass of protons. A current of protons is sent into a chamber with a negatively charged plate. The plate has a hole in the middle, so the protons will speed forth in a straight line. Then neon atoms then bump off the electron--from a proton? I'm totally confused. I don't know what is sent into the apparatus to start--electrons, atoms? / The plate is positively charged, which means that negatively charged ions must be sent into the apparatus, to shoot through the hole, be bumped with neon, and become-pretens <sup>neon becomes</sup> positively charged ions. But-how-does-one-turn-a-negative Neon's electron is bumped off and it becomes a ion-into-a--proton-by-introducing Neon ions neon? Anyhow, the pretens are then deflected by a magnetic field

5

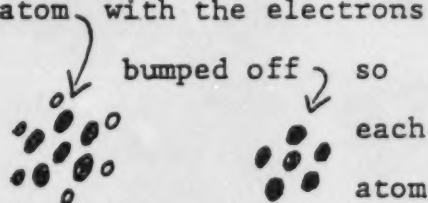
10

15

20

See  
 \*  
 over

outside the apparatus. The variables  
of mass and charge are the most  
significant. Those with higher charge 25  
have a higher deflection, (farther  
to the right, closer to the negative  
magnetic field) The heavier ones  
deflect less, and a ratio can be  
set up to balance between mass 30  
and charge to see how they can  
land in different places. Using known  
elements, a scale was set up so  
unknowns could be calibrated.  
Each proton has the same mass, 35  
but different atoms have differ-  
ent numbers of protons, thus  
different masses and different  
readings on the spectrograph. → BUT  
this is ~~wrong~~, because indiv- 40  
idual protons have the same  
mass. wait--we're talking about  
an atom with the electrons



has a different mass, thus 45

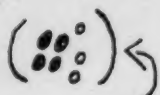
the different readings. O. K.

The charge is simply how many

more positive protons than

50

electrons or vice versa. It

is simply a representation. 

despite the real charge, this is +1.

Millikan's drum had one neg. and one pos.

plate and a negative charge on

55

the oil drop. The drop was attracted

up toward the plate, but pulled down

by gravity and the other charge,

so it became stationary.

## CONCLUSION

### Conclusions drawn from case studies

Students who wrote to think about chemistry:

- wrote when they felt confused and needed to get material straight.
- were interested in understanding, not just in memorizing the material.
- wrote for themselves.
- wrote to themselves.
- needed to see the material in their own words and in their own order of thought, not only in the words and order in which the material was presented.
- didn't need to write about all the material.
- wrote when they were rested.
- wrote when there were few internal or external distractions.
- drew diagrams and wrote evaluative comments to themselves about the material.
- needed encouragement because writing to think is hard.

- sometimes used their writing later to check or refresh their memories.
- thought others would be critical of their writing and not be able to read or understand the information.
- didn't need the teacher to explain things over and over.
- didn't always find it necessary or convenient to keep all the writings.
- asked well thought-out questions.
- figured out material without the teacher's help.
- delighted in their ability to learn and understand chemistry.
- took responsibility for their learning.

What happened to the researcher when she wrote to think about chemistry

I wrote when I had been presented with a lot of material or difficult material. Usually introductory material was uncomplicated and I could do the thinking in my head. But when we got into new vocabulary, new concepts, new details, new processes, I found myself needing to write.

Things were never quiet enough in the classroom for me to write successfully. If it weren't the other students' talking, it was the talking going on in my own head which

disturbed me. My head needed peace both externally and internally for it to think about chemistry. I couldn't do it when other things were pressing on my mind. When the teacher gave us ten minutes at the end of class to write, I was still too overwhelmed by all the new material to know where to begin. I needed distance and time from it before I could think about it again. My brain needed a rest. Sometimes I was too preoccupied thinking about something else, such as, what I was going to do after class. I couldn't get my mind to focus on chemistry. But if I had enough time I could usually write the things out of my head which preoccupied me so that I could get to the ideas in there about chemistry. Sometimes when I was able to write chemistry, I invariably ran out of time and left class frustrated. And when the teacher gave us ten minutes at the beginning of class to write, I usually sat through the remainder of the class struggling to concentrate on the lesson because I was still thinking about the chemistry I had been writing about.

I often felt that had I not been writing while I learned chemistry, I would not have worked with difficult ideas as long as I did without getting help. I often rely on others for help when I think something is too difficult for me to do on my own or when I need to hear myself talk so I can know what I know. My urge to talk about anything

I learn is very strong. I believed that chemistry was difficult so it would have been natural for me to seek out a willing helper and ear. But when I did the writing, I no longer felt I needed another person. The writing enabled me to know what I knew and to figure out the difficult ideas on my own. I realized I could listen to myself think while I wrote my ideas on the paper.

I wrote down whatever I thought, as if I were trying to capture the flow of ideas in my brain on the paper. Sometimes I captured tangential thoughts which always proved to be useful and interesting. Frequently, I "captured" ideas which didn't make sense, or sounded silly, or were wrong. When this happened, my internal critic or common sense, for lack of a better word, interrupted the idea with an evaluative comment. I would write the evaluative comments on the paper as well. If the internal critic remarked "that doesn't seem right," I'd write "that doesn't seem right." I learned quickly to trust my internal critic's intuition. And my internal critic didn't only tell me when I was wrong. She often made comments of encouragement, such as "I think I'm getting it" which kept me going when I was on the right track.

I didn't cross out the nonsensical, silly or wrong things I wrote. I also didn't cross out the internal critic's comments. I just went on writing. Crossing out

wasn't necessary. I wrote not because I wanted to get all the ideas clear and correct on the paper but because I wanted to get all the ideas clear and correct in my head. It wasn't important that no one else would be able to read my writing and understand what I was saying about chemistry. What was important was that I understood what I was saying by the time I'd completed the writing. The writing was for NOW, at the time I was doing it, not for later, and the writing was for me, not someone else.

When I wanted to think, I didn't always write in my thinkbook. I wrote on my homework sheet or on the back of my test, on whatever paper was immediately available. I also liked keeping the writing with the other information which had started me thinking.

If it wasn't clear and perfect in my brain, I formulated questions I needed answered by the teacher to get it that way. Most of the questions required yes or no answers, such as "is this right so far?" All I wanted or needed was the teacher's simple response. I didn't want her to explain why it was wrong or what happens next. I didn't want her to take my knowledge out of my hands at that point. I wanted to figure out why it was wrong or what happened next. I needed her simple direction and then I wanted to get back to work with my ideas, my words and my train of thought. I wanted to get back to my desk and write. Once

she gave me my lead, I couldn't hear what else she explained because I was listening very hard to what was going on in my own head. I couldn't use any additional ideas until I had thought through the implications of the answer she had given me to my question. To use an analogy, she was giving me more than I could chew at that time. I had no room for more. I had to swallow what I already had before I could take in any more. I knew when I was hungry for more, I would get it.

When I wrote I also felt as though I let the ideas at the forefront of my brain out onto the paper so that the ideas in the back of my brain could move up into the front. Once those first ideas, the conscious ones, were out of my head, the ideas in the back of my brain, the subconscious ones, had room to move to the forefront to become the conscious ideas. And when I wrote these out, more ideas moved into the forefront. The new ideas had been too far in the back of my brain, and I couldn't get to them until I made room.

With all those new ideas now available to me, I felt as if I was discovering new things about chemistry which I didn't know I knew. At the same time, I was making connections between one bit of information and another, sorting and reshuffling and discovering even more. When I transferred the idea to paper, I could actually see what I

knew about the idea. Seeing that I knew something about the idea and seeing precisely what I knew, whetted my appetite to see what else there might be rattling around in my brain about the idea. As an experiment I tried using a tape recorder to see if it would give me the same benefit. Although I could hear what I knew as I talked into it, I missed not being able to see what I knew, even though I could hear it again. In addition, when I wrote my ideas I could much more easily look up the page to see an idea than I could rewind the recorder to find the exact place where I could hear the idea. I ended up transcribing onto paper the tape recordings I made so I could work with them more easily.

The beauty of having it on paper was that I felt as if my brain was freed of a lot of the information it had been storing so that it could work more spontaneously with the ideas on paper. I could arrange and rearrange the sentences and ideas and fill in the gaps with additional ideas as it worked towards making everything make sense together. Because it was on paper, I was able to work back and forth between paper and head until I had everything out on paper and it all clicked.

I found that writing eliminated all my need to study the night before a test. I knew and understood everything already. I didn't need to memorize anything or cram

anything into my head; and, because I didn't have any information precariously and hurriedly jammed into my head, I knew that I couldn't forget it in the middle of the test. I knew I had it all in there in order, so it made sense, and I could call upon it and find it when I needed it. It was all neatly filed, not just thrown in. I was confident in this knowledge and in my knowledge. All the pressure I'd always associated with tests vanished.

For me, writing was like putting together a jigsaw puzzle. The teacher showed me the picture on the box (the text) and showed me her own completed puzzle (her lecture). With these general impressions of what my own puzzle should look like, I laid out my own pieces. As I did, I arranged the pieces into groupings. Some linked together. Then I concentrated on the border and worked from there. If I got stuck, I consulted the picture or the teacher's completed puzzle. She looked at my puzzle, but I didn't want her to put it together for me. As more and more pieces fit, I worked more rapidly and contentedly. When I was finished, I kept my completed puzzle and the knowledge that I had done it myself.

The very best part for me was that I realized I could actually think well enough on my own to figure something out without someone else showing me the direction or giving me clues. I could think well enough to ask questions which

were right on point. The writing had eliminated my anxieties about chemistry, a subject I wasn't supposed to be able to do. It gave me confidence in my ability. I felt independent. I felt free. I could understand chemistry on my own. And if I could do chemistry, what else could I do on my own? I suddenly wanted to try more and difficult things. I was delighted about my ability and amazed at my knowledge. I knew I had done it all by myself.

What happened to the other students and why

About one-third of the twenty-six students in the class were so unsure about what writing to think meant, they didn't write anything. Others wrote to me and for me, pretending I was not a member of the class and informing me about what was happening. In school, students write for this purpose almost exclusively, pretending someone else, usually the teacher, is uninformed and writing to him about a subject he already understands.

Students who were concerned about their grades wrote to memorize and/or wrote to check their recall of the material. In a sense, they were actually "writing to learn," i.e., memorize. They knew there is a relationship between the act of writing and the ability to remember. Before a test, these students wrote everything they could remember to see if the information in their brains was

factually accurate and complete. They didn't write information they were uncertain about until they consulted their notes for the teacher's explanation. They didn't want to write anything wrong. They crammed the teacher's words into their writings and their heads. They wrote as if the teacher would read and correct their written products. Some teachers encourage their students to write for themselves for these purposes.

Only four of the twenty-six high school age students were able to write to think. I was very curious to know why the majority could not. My first guess was that I had erred in my description of the purpose for the writing. I did not know the term, "write to think," until after I completed my work with the students. However, three students had done it without knowing the most succinct words to describe what they did. These students shared a desire to want to understand chemistry. But, there were others who wanted this as well. With Piera as the exception, NONE of them had ever written to think before. But, even Piera wasn't convinced that the writing she had been doing for over two years was a legitimate use for writing. Until she came into the chemistry class, she had never discussed her writing with anyone nor heard writing discussed in this way. In fact, she had not thought of the writing she was doing as thinking. So that, my second thought as to why the

majority didn't write to think is that none of them knew that writing is thinking.

The students viewed writing as the act of putting ideas on paper which already make sense and which the writer wants to record for others to read. Our society holds the same belief. We see writing as a final offering of ideas which a writer makes to his readers. We assume the writer has conceived of and organized the ideas in his head before he ever commits them to paper. We teach this to our students. They remain unaware that writing can have another legitimate purpose. They don't know they can write ideas which don't already make sense in their heads before they put them down on paper. They need to know that it is worthwhile for them to write down these mixed up ideas, in the circles they come in, in the repetition they come in, in the words they come in, in the order they come in. They need to know these written mixed up ideas don't have to be seen by anyone else or make sense to anyone else. Their ideas are meant only for themselves. They can write at any time, anywhere, in any way, to figure anything out. Their ability to write is theirs to own and to control. They need to know that they can write without someone else dictating that they write, or how, what, when, where, and why they write. There is no question in my mind that when they know these things, they will be able to think and write.

### Suggestions to teachers

I suggest that writing is a means which teachers have long ignored as a way for students to approach the learning of a subject. It should not be ignored any longer.

I strongly suggest teachers themselves experiment with writing while encouraging their students to do the same. Because the teacher already understands the subject he teaches, he will want to write about other material he has or is being presented which he wants to understand better. He might write about a personal dilemma, his graduate school work, or a student he wants to understand better. I believe that many teachers will find "writing to think" an exciting means of understanding information for themselves and won't need to be convinced by my research to encourage their students to write. They will want to offer it to their students. As the students write for themselves, the teacher will come to find, much to his relief, that he no longer must take so much responsibility for his students' learning. As it is now, teachers feel that they must pose questions to their students to which they themselves know the answers for the purpose of discussing information. The teacher asks and the student is supposed to respond with the answer. Now, if students write to think, they will begin, as illustrated by Laura and Tim, to ask authentic questions which they have discovered in

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the process of puzzling out, straightening out, and getting to the bottom of the material while writing. The teacher will no longer pose the questions, the student will. In other words, the person who genuinely doesn't know the answers will be asking for them. And the student won't always have to ask the teacher for the answer. The student will begin, as exemplified by Laura and Tim, to pose the question first to himself and then to try to figure it out by writing. He will take pride in finding the answer himself or in finding the key questions about which he needs further information to go on and find the answer. He will want to take responsibility for his learning.

For teachers who want their students to try writing to think, I'd like to offer a few words of advice. I think it's too much to say that students should write every day. Writing to think needs to be done while the material is being presented, not in a rush before a deadline or a test. The mind doesn't seem to be able to efficiently sort out a lot of information in a short period of time. The mind needs time to play with information before it can make sense of it. Students need to do the writing when the material becomes confusing to them -- that is, when they start to have questions. Only the student can know when he has a question so it is his responsibility to write when he feels the questions arise. However, I believe it is possible

for the teacher to anticipate the problems and confusions a student might have. From the teacher's experience, he can anticipate where students tend to become confused about particular material. He also may know a student's ability and self-confidence with certain types of material to guess when he will have problems. As a writer and as an objective observer, the teacher, who is in tune with the material and his students, may know when a student needs to write, just as he has developed an ability to know what material he needs to present and when the student is ready for more.

Obviously the maturity of the student will have a direct bearing on how much direction and encouragement in writing the teacher needs to give. The inexperienced thinker will need more help. But he will become more responsible for his writing and learning as he feels good about his ability to write and to learn. He'll want to take more responsibility for his mind and its learning because he gets more in return when he does. The responsibility and love the student feels for his brain and its ability increases in proportion to the pride he feels about his ability and himself.

There is no reason to write in a bound volume. I quickly went to a loose leaf binder so that I could write on any available paper and put it all together later. I also didn't have to carry my thinkbook with me. I found

advantages keeping it in one place. I occasionally re-read sections as review, but particularly enjoyed looking back out of curiosity to see how I came up with some of my ideas. I felt proud to be able to hold in my hands pages and pages of chemical thinking that I did on my own without help.

Many students might never need nor want to show their writing to their teacher. When they come to a specific question, it may be easier and more efficient to ask it out loud. But when the confusion is bigger, it may be easier and more efficient to literally show the confusion to the teacher by letting him read the writing.

The teacher whose student asks him to read his writing must keep in mind at all times the purpose of writing. He must also keep in mind his purpose for reading it. Only the asking student can know this and needs to tell the teacher his purpose. If the student doesn't explain why, then the teacher needs to ask, "Why do you want me to read this? What is your question or problem with it?" The student might respond, "I want you to see if what I have makes sense," or "I can't figure out what I'm doing wrong." The teacher then knows his purpose for reading.

In any case, the teacher needs to read the writing with his attention focused on the process the student went through in thinking through the material. The teacher will

be of no help to the student if he reads with his attention focused on the product itself. The teacher will not help the student by reading the writing and suggesting line by line revisions and corrections in the ideas and logic. The teacher will help the student by reading the writing slowly and thoughtfully in its entirety a couple of times, keeping in mind the purpose the student has given him for reading. He must also remember that the sentences and logic the student writes on the paper correspond directly to the ideas the student is thinking. The student is think-writing because he is weak and unclear in his understanding of the material. Thus his writing is weak and unclear. As he continues to write, he begins to get stronger and clearer in his understanding. Correspondingly, the words, sentences, and logic on the paper begin to get stronger and clearer. The teacher will be able to see this progression of thinking and understanding on the page. By carefully reading the writing, the teacher will know what the student is thinking. By carefully reading the writing, the teacher will know what the student knows. And, the teacher will know what the student doesn't know. He will know why the student has asked him to read the writing or why the student has asked him a question. The teacher will know how he can best assist each student in further understanding the material. He can pinpoint the information the student doesn't yet have straight or now needs.

He will discover clues the student leaves behind which may indicate what help he needs. Questions or question marks are overt clues as to the student's confusion. Vague words, incorrect information, illogic, critical asides, or tangential thinking are less obvious clues as to what may be confusing the student. Even crossed out words or sentences may provide hints as to what the student doesn't understand.

The teacher must remember all think-writing is by nature difficult to read, from the handwriting, to the spelling, to the organization. The most difficult reading is at the beginning where the most difficult thinking was happening in the student's head. But for the teacher who takes the time to read and sticks with it, the rewards will be enormous. The teacher will be able to give to each student his very own special, individual KEY to understanding the material. With his own key, each student will be able to unlock his own doors and go on learning and understanding more material without needing or wanting the teacher's help.

Okay —

$$1 \text{ km} = 1000 \text{ m}$$

$$1 \text{ hm} = 100 \text{ m}$$

$$1 \text{ dk} = 10 \text{ m}$$

$$10 \text{ km} = 1 \text{ m}$$

$$100 \text{ cm} = 1 \text{ m}$$

$$1000 \text{ mm} = 1 \text{ m}$$

So far so good —

Now —

$$10 \text{ m} = \text{ — km}$$

$$? \text{ km} = 10 \text{ m} \left( \frac{.001 \text{ km}}{1 \text{ m}} \right)$$

$$\begin{array}{r} .001 \quad 3 \text{ sig. figs} \\ \times \quad 10 \quad 2 \text{ sig figs} \\ \hline 000 \\ 001 \\ \hline .010 \end{array}$$

$$.01 \text{ km} = 10 \text{ m}$$

I did it!

$$? l = 250 \cancel{\text{ml}} \left( \frac{1 l}{1000 \cancel{\text{ml}}} \right)$$

$$? l = \frac{250}{1000}$$

$$l = .250$$

$$.25 l = 250 \text{ ml}$$

$$? kg = 2000 g \left( \frac{.001 kg}{1 g} \right)$$

$$2 kg = 2000 g$$

I think I'm catching on

$$? cl = 10 \cancel{\text{ml}} \left( \frac{1 l}{1000 \cancel{\text{ml}}} \right) \left( \frac{100 cl}{1 l} \right)$$

$$= \frac{10 \times 100}{1000}$$

$$= 1 cl$$

$$1 cl = 10 \text{ ml}$$

all right!

$$? \text{ dl} = 7.7 \cancel{\text{L}} \left( \frac{10}{1 \cancel{\text{L}}} \right)$$

$$7.7 \text{ dl} = 7.7 \text{ L}$$

Just remember to place the units in the right order so you can cancel out. Remember to go up to major unit if necessary & then proceed.

I better pass this down to quiz  
Don't forget!

All digits are sig. figs

All zeros between 2 #'s are  
sig figs

All zeros after a # & after a  
decimal are sig figs

All zeros after a # & before  
a decimal are sig figs

$\mu$  = micro

$\text{mm}$  = micrometer

Don't forget to pretend  
that the ball is really  
a particle!!!

Thomson  $\Rightarrow$

O.K. He did an experiment  
w/ a ball + a magnetic field.

If  $\Rightarrow$  the ball is charged, there  
is a greater attraction  
between the ball + magnetic  
field. Why? Because  
electricity interacts w/ a  
magnetic field.

O.K. What if the mass of the  
ball was changed? The  
magnetic field would have  
a harder time attracting the  
ball. So — (I forgot  
about deflection)

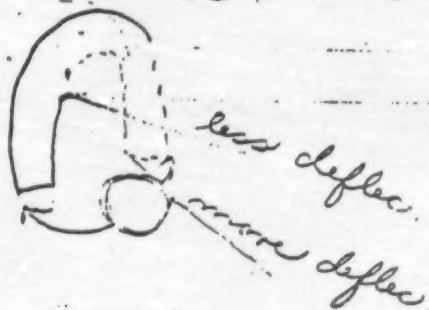
Deflection is a change in  
direction. Thomson  
found in his experiments  
that deflection was the  
arc of a perfect circle.  
(Smart guy!)

Now  $\Rightarrow$  As the ball w/ the  
larger mass goes through,  
the deflection goes down.

Wait, that doesn't make  
sense.

As mass of ball  $\uparrow$ ,  
deflection  $\downarrow$   
or

It takes longer for the  
magnetic force to  
attract the ball (Why?  
because of the added  
weight)  $\therefore$  the deflection  
or arc is not as curved.



If the balls speed is increased then deflection is less again. Because it takes longer for the magnetic field to attract it.

If the magnetic field is increased then the ball will have a greater deflection because the attraction is greater.

So far - 4 variables involved

- 1) charge of moving particle
- 2) speed of moving particle
- 3) mass of particle
- 4) strength of magnetic field

The amount of deflection can be measured

So 5 variables now.

deflection is proportional  
to the charge of the particle  
+ the strength of the  
magnetic field

$$d = eB$$

deflection is inversely  
proportional to the mass  
and velocity of the particle.

$$d = \frac{1}{mv}$$

Combine Equations

$$d = \frac{eB}{mv}$$

Can deflection be calculated? <sup>yes</sup>  
Can the charge of the particle  
be calculated? no  
Can the magnetic field be  
calculated? yes

Can mass of particle be  
calculated  $\Rightarrow$  no

Can speed of particle be  
calculated  $\Rightarrow$  yes

So. 2 unknowns

$$\frac{e}{m} \Rightarrow 1.75 \times 10^8 \frac{\text{Coulombs}}{\text{grams}}$$

How this equation?

Well, Thomson found  
that  $\left(\frac{e}{m}\right)$  always was a  
constant of  $1.75$   
 $\times 10^8 \frac{\text{Coulombs}}{\text{grams}}$

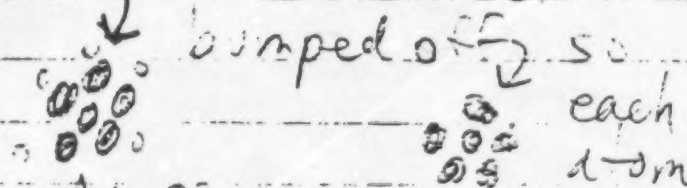
What did it prove?

- 1) All electrons same
- 2) Found way of determining  
ratio in hopes that  
 $m + e$  would be known  
values.



ion into a proton by introducing  
 neon? Anyhow, the <sup>Nash ions</sup> ~~ions~~ are then  
 deflected by a magnetic field  
 outside the apparatus. The variables  
 of mass and charge are the most  
 significant. Those with higher charge  
 have a higher deflection (farther  
 to the right, closer to the negative  
 magnetic field) The heavier ones  
 deflect less, and a ratio can be  
 set up to balance between mass  
 and charge to see how they can  
 land in different places. Using known  
 elements, a scale was set up so  
 unknowns could be calibrated.  
 Each proton has the same mass,  
 but different atoms have differ-  
 ent numbers of protons, thus  
 different masses and different  
 readings on the spectrograph. → BUT

this is wrong—because individual protons have the same mass. wait—we're talking about an atom with the electrons



has a different mass, thus the different readings. O.k.

The charge is simply how many more ~~protons~~ protons than electrons or vice versa. It

is simply a representation. (⊕) despite the real charge, this is +1. Millikan's drop had five neg. and one pos. plate and a negative charge on the oil drop. The drop was attracted up toward the plate, but pulled down by gravity and the other charge, so it become stationary.

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